RESEARCH ARTICLE

Effect of near canopy thermal changes on growth, yield and grain sterility of three ultra-short age rice varieties under aerobic and flooded conditions

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ABSTRACT

Canopy temperature (CT) represents the temperature experienced by the uppermost portion of the vegetative canopy of a crop. CT may better explain the high temperature-induced grain sterility and yield losses than air temperature does. However, less scientific attention was paid on CT related investigations on rice under Sri Lankan context. Therefore, Sri Lankan rice varieties were evaluated at the Rice Research and Development Institute, Bathalagoda under two soil moisture conditions to study the canopy thermal dynamics and its impact on growth, grain sterility and yield. This Experiment was arranged in a two-factor factorial Completely Randomized Design with eight replicates. Factor one was soil moisture condition (aerobic and flooded) and factor two was rice variety (Bg 250, Bg 252 and Ld 253). CT was continuously monitored at 10 minutes intervals. Growth and yield parameters were recorded once a week. Number of tillers was negatively correlated with maximum CT while plant height was positively correlated with minimum CT in both conditions. CT at spikelet opening had a negative impact on pollen fertility and positive impact on grain sterility irrespective of moisture condition. Under flooded condition, grain yield was negatively correlated with maximum CT at 13:00 h. Moreover, growth and yield performances were superior under flooded conditions compared to aerobic conditions. Interactive effect of soil moisture × variety was significant for 1000-grain weight and % pollen fertility where the highest values were recorded by Bg 250 (29.33 g) and Bg 252 (96.4%) in flooded conditions, respectively. In conclusion, monitoring CT dynamics can be considered as a useful tool to assess growth and yield performances of rice under varying soil moisture conditions. Field investigations are suggested to confirm the results.

Keywords: *Aerobic and flooded conditions, canopy temperature, grain sterility, pollen fertility, rice* (*Oryza sativa*)

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for about 20 million inhabitants of Sri Lanka. It is the single most important crop occupying 34% of the total cultivated area in Sri Lanka. Annual per capita rice consumption in Sri Lanka is approximately 110 kg (DOA, Sri Lanka, 2017). Rice is cultivated in almost all parts of the country (Henegedara, 2002). Although, rice is well adapted to diverse environments, rice is highly susceptible to heat (Satake and Yoshida, 1978). Excess heat, even its duration is short, it can reduce crop yield (Wahid *et al.*, 2007). In tropical humid rice-growing ecosystems, high temperature-induced grain sterility in rice has become a serious field problem, making whole rice fields almost completely sterile not only in the midland and upland areas but also in the lowland region in recent years. Thus, it directly affects the yield losses and rice productivity. This may be due to the combined effect of high temperature and high relative humidity (Abeysiriwardena *et al.*, 2002). However, observational evidences indicated that crop canopy temperature better explains grain sterility and the yield reduction associated with high temperature events than air temperature does (Siebert *et al.*, 2014).

Canopy temperature is the temperature experienced by the uppermost portion of the crop canopy. Canopy temperature is a better explanator of the changes in canopy level microclimate. Therefore, measuring canopy temperature rather than air temperature is important in evaluating the temperature effect on rice. However, canopy temperature related investigations on rice are limited under Sri Lankan context. Therefore, in the current study, three Sri Lankan rice varieties were tested under two soil moisture conditions with the objective of investigating the thermal changes inside the canopy and its impact on growth, yield and grain sterility. The specific objectives were to determine (1) the growth and yield performances of three ultra-short age rice varieties (2) the effect of canopy temperature at spikelet opening and closing on pollen fertility and grain sterility (3) the dry matter partitioning under aerobic and flooded conditions and (4) the ideal variety that shows better performance under aerobic condition among the selected ultra-short age varieties.

MATERIALS AND METHODS

Experimental location

This research was conducted inside a plant cage at the Rice Research and Development Institute (RRDI), Bathalagoda (7.5315°N, 80.4354°E) during August to December in *Maha* season 2019. It is located at Kurunagala district and belongs to Low Country Intermediate Zone of Sri Lanka. Annual average temperature is 27.2 °C and average annual rainfall is about 2000 mm. Soil type is Red-Yellow Podzolic associated sandy clay loam soil.

Experimental design and procedure

The experiment was laid out in two-factor factorial, completely randomized design (CRD) with eight replicates. The two factors were soil moisture conditions (aerobic and flooded) and rice variety. A total of 48 pots (22 cm deep with 24 cm diameter at top) were used. Seeds of three ultra-shortage rice varieties (Bg 250, Bg 252 and Ld 253) were sown and 14 d old seven seedlings were transplanted in each pot. Two levels of moisture conditions were imposed separately at tillering stage and maintained throughout the experiment. To impose flooded condition 5 cm water column was maintained above the soil surface in 24 pots. The remaining 24 pots were maintained under aerobic condition where soil had 20% volumetric moisture content with no water layer above the soil surface.

Data collection

Growth parameters

Plant height and tiller count per pot were recorded continuously from tillering to flowering stage. Flag leaf length at flowering stage were measured. Culm diameter was measured using a micrometer screw gauge from late booting to maturity stage. Spikelet opening period and duration were determined by observing randomly selected 30 plants from each treatment combination at the heading stage.

Morpho-physiological parameters

Greenness was measured using a SPAD-502 chlorophyll meter (Konica Minolta, Japan) in flag leaf of the middle plant (average value of tip, middle and base portions of the flag leaf) in both aerobic and flooded conditions from late booting to grain filling stage using eight replicates.

Canopy level temperature was continuously monitored at 10-minute intervals by using a Micrometeorological Instrument for Near Canopy Environment of Rice (MINCER, developed by National Institute of Agro-Environmental Sciences, Japan) coupled with Logistic control®V 0.09 data logger (MonotaRO Co., LTD, Japan). Two MINCERs were installed just above the panicle level of rice plant population inside the plant cage in both conditions which was the micrometeorology of the near canopy area directly experienced.

Pollen fertility was recorded after flower synchronization. At the time of anthesis (spikelet opening), 30 representative spikelets from 30 rice plants were collected from each treatment combination and spikelets were cut and put into 70% ethanol solution to protect the viability of rice panicle. Pollen grains were collected from the representative spikelets of the second or third branch from top on the primary rachis. Anthers were carefully removed and placed on the glass slide, and two to three drops of 1% I_2-KI solution were added (Sarial and Singh, 2000). Then anthers were crushed and covered using coverslip. Observations were taken using a microscope. Pollen grains which stained in dark colour were counted as fertile. Percentage of pollen fertility was calculated using the following equation (Singh *et al.*, 2014).

$$\text{Pollen fertility (\%)} = (\text{Number of fertile pollen}/\text{Total number of pollen}) \times 100$$

Dry matter partitioning was studied by measuring the dry weight of leaf, sheath, stem, and panicle by removing three pots per each treatment combination separately (total of 18 pots) at flowering and maturity stages using oven-dry method and temperature was maintained at 65 °C.

Yield parameters

Yield attributes were recorded at maturity only. Each pot was harvested separately at the rice maturity and 1000-grain weight, number of panicles per pot, spikelets per panicle and weight per panicle were measured. Percentage (%) of filled grains were calculated as the number of filed grains per panicle multiplied by a factor of 100 over the total number of filled grains per panicle (Wiangsamut *et al.*, 2013).

$$\text{Filled grains (\%)} = (\text{Number of filled grains/Total number of grains}) \times 100$$

Grain sterility was recorded using backlight at 14 d after heading in tagged panicles from randomly selected 30 plants from each treatment combination and number of sterile, partially fertile and fully fertile spikelets were counted. Grain Sterility Index (GSI) was calculated using the following equation.

No embryo development – Sterile-5
Embryo developed partially – Partially fertile-3
Full embryo development – Fully fertile-0

$$\text{GSI} = \frac{(0\times\text{Fully fertile})+(3\times\text{Partially fertile}) +(5\times\text{Sterile})}{(5\times\text{Total number of spikelets})}$$

Data analysis

Data were subjected to analysis of variance (ANOVA) using MINITAB 17 statistical software. Tukey's mean comparison was done to test the significant difference at 0.05 level of significance. Correlation analysis was used to identify the following relationships.

- Canopy temperature *vs*. growth, yield, and grain sterility
- Canopy temperature at spikelet opening and closing *vs*. grain sterility and pollen fertility

RESULTS AND DISCUSSION

Growth and Morpho-physiological parameters

Plant height, tiller count, flag leaf length and chlorophyll content

Interaction between soil moisture condition and variety was not significant for plant height, tiller count per pot, flag leaf length and chlorophyll content (greenness) (P>0.05). However, the results revealed that those parameters were significantly influenced by soil moisture conditions (P<0.05) where the lowest values were recorded under aerobic condition compared to flooded condition in all three varieties (Figure 1 A-D). The decrease in plant height in aerobic condition might be either due to inhibition of length of cells or cell division under water deficit conditions (Islam, 1999). Reduced tiller production under lower soil moisture levels might be due to inhibition of cell division of meristematic tissue (Islam *et al.*, 1994). As per the results, significant differences were not observed among the rice varieties in terms of plant height, number of tillers per pot, flag leaf length and chlorophyll content.

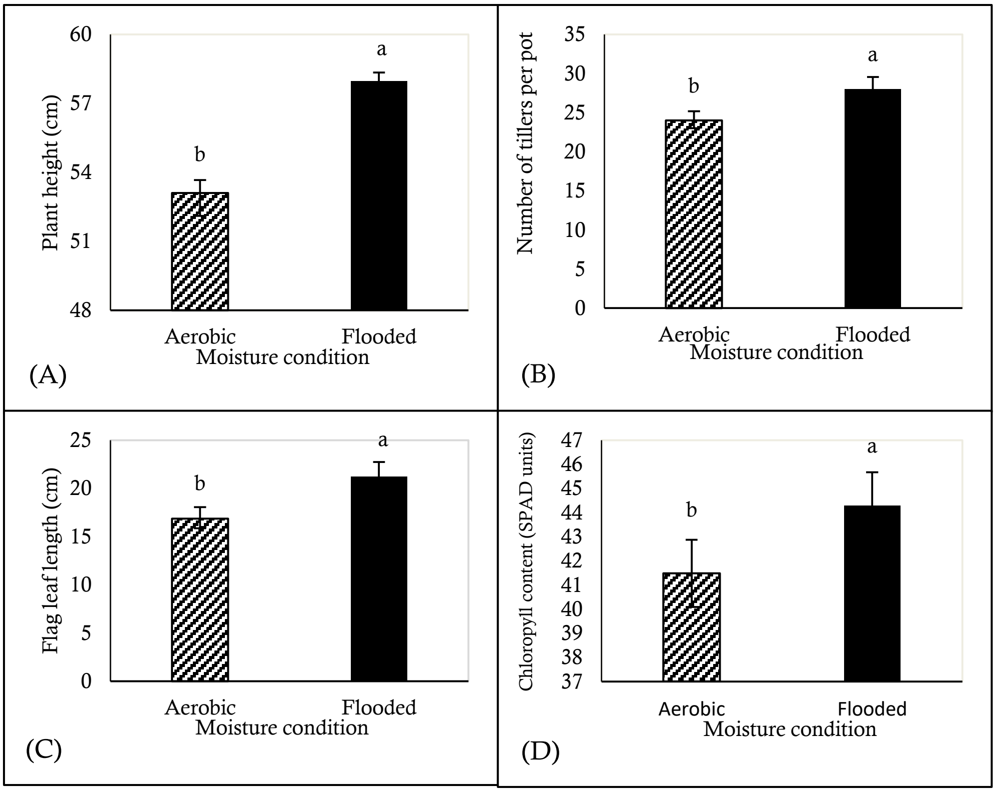


Figure 1: Plant height (A - at 7WAT), Number of tillers per pot (B - at 6WAT), Flag leaf length (C - at 7WAT) and Chlorophyll content (D - at 7WAT) across the three ultra-short age rice varieties (Bg 250, Bg 252 and Ld 253) under aerobic and flooded conditions. WAT-Weeks after Transplanting (Means with the same letters are not significantly different at 0.05 probability level).

Pollen fertility percentage

The results revealed that the interaction between soil moisture condition and variety significantly ($P<0.05$) influenced the pollen fertility (Figure 2). The highest %pollen fertility was recorded by Bg 252 under flooded condition. Rice exposed to water deficit during anthesis shows pollination abnormalities that leads to lower grain yields (Ekanayaka *et al.*, 1989).

Furthermore, water deficit may induce pollen abortion in rice (Nguyen *et al.*, 2009). These factors might have contributed for the observed differences in % pollen fertility in this study.

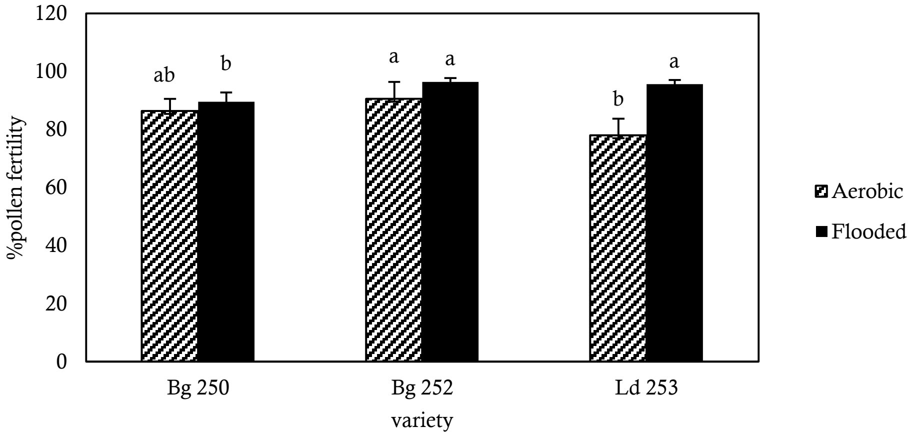
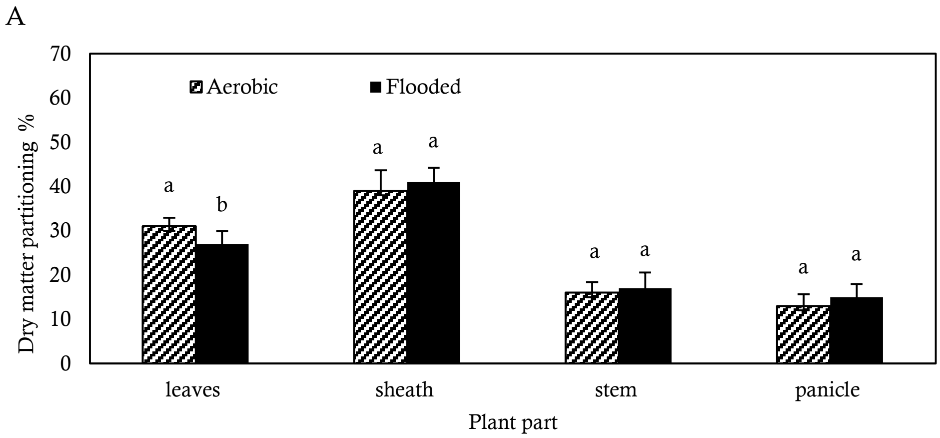


Figure 2: Pollen fertility of three ultra-short age rice varieties (Bg 250, Bg 252 and Ld 253) under aerobic and flooded condition. Means with the same letters are not significantly different at 0.05 probability level.

Dry matter partitioning

At both flowering and heading stage, there was no significant (P>0.05) difference in percent of dry matter partitioning into leaf, sheath, stem and panicle under two soil moisture conditions and three rice varieties. The dry matter partitioning into sheath was higher compared to other parts of the plant at flowering stage (Figure 3). Conversely, at maturity stage, more dry matter was partitioned into panicles. Among the three varieties, Bg 250 partitioned more dry matter into panicles than Bg 252 and Ld 253 at maturity stage. The higher dry matter partitioning into reproductive parts (panicles) increases the grain weight, grain length, grain yield, 1000-grain weight. Donald and Hamblin (1976) found that grain yield in cereal was related to biomass yield and harvest index. Increase in dry matter accumulation and partitioning was more important because it is significantly associated with grain yield (Hasegawa, 2003).



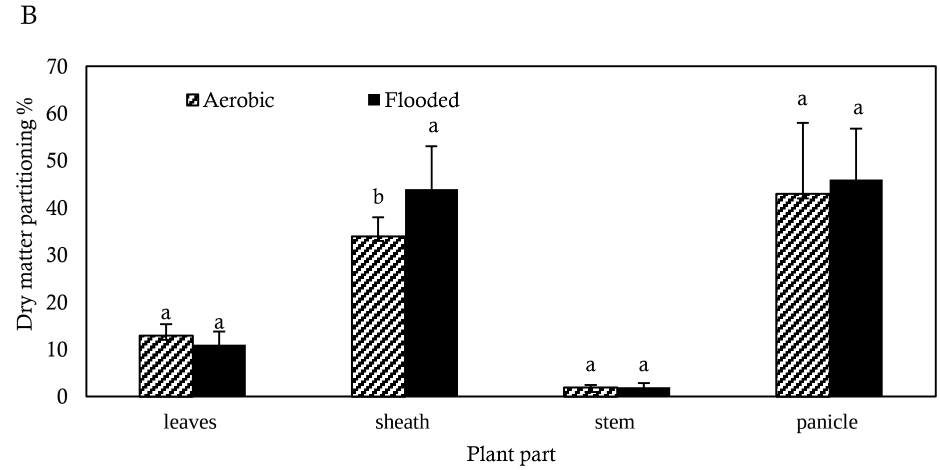


Figure 3: Dry matter partitioning (%) of three ultra-short age rice varieties (Bg 250, Bg 252 and Ld 253) under aerobic and flooded condition at flowering (A) and maturity stages (B) (Means with the same letters in each graph are not significantly different at 0.05 probability level).

Yield performance

Thousand grain weight

Thousand grain weight, which is an important yield determining component, is a genetic character influenced by the environment. There was a significant (P<0.05) interaction effect of soil moisture condition and variety on 1000-grain weight (Figure 4). The highest value of 1000-grain weight was recorded by Bg 250 under flooded condition. Bg 252 recorded the lowest value under both conditions. The results showed that 1000-grain weight was reduced with aerobic condition compared to flooded condition in all three varieties. However, the degree of reduction in 1000-grain weight was different among varieties ranged from 9.1% decrease in Bg 252 to 22% decrease in Bg 250. Visually, seeds of Bg 250 were bolder and thicker, while Bg 252 seeds were relatively smaller, having typical long grain rice appearance. Reduction in 1000-grain weight under low soil moisture may be due to the decrease in translocation of assimilates to the grain which lowers the grain size. Water stress negatively affects on grain weight (Islam *et al.*, 1994b; O'Toole *et al.*, 1979; Tsuda and Takami, 1991). Yoshida *et al.* (1981) suggested that 1000-grain weight of rice is mainly affected by the hull size that is genetically controlled.

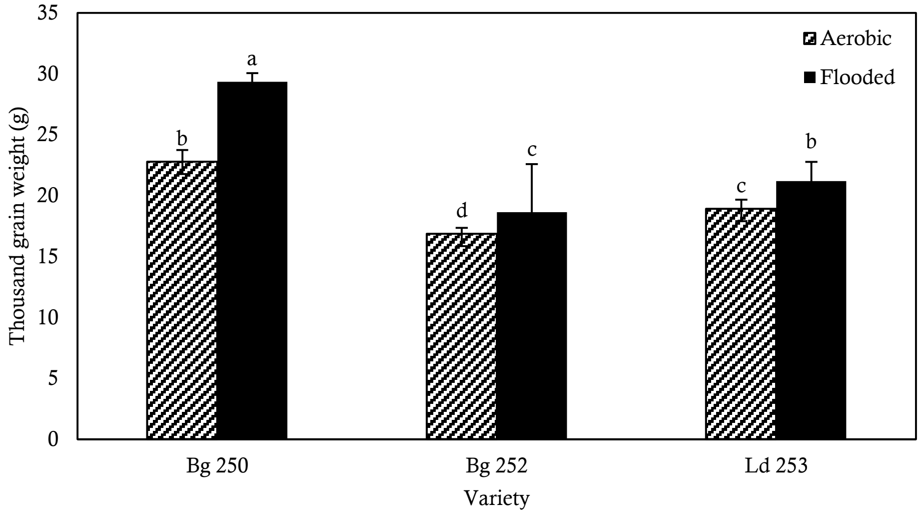


Figure 4: Thousand grain weight of three ultra-short age rice varieties (Bg 250, Bg 252 and Ld 253) at maturity stage under aerobic and flooded conditions. Means with the same letters are not significantly different at 0.05 probability level.

Number of panicles per pot

The results revealed that the interaction between soil moisture condition and variety was not significant ($P>0.05$) on number of panicles per pot (Table 1). Although, the number of panicles per pot was not significantly ($P>0.05$) affected by the variety it was significantly ($P<0.05$) affected by the soil moisture condition. The panicle number was significantly ($P<0.05$) higher in flooded condition than aerobic condition. This result agrees with the previous findings of RRDI (1999) which stated that water stress at or before panicle initiation reduces panicle number.

Number of spikelets per panicle

There was no significant ($P>0.05$) interaction effect of soil moisture condition and variety on the number of spikelets per panicle (Table 1). The varieties differed significantly ($P<0.05$) in terms of number of spikelets per panicle, ranging from 81.2 in Ld 253 to 102.7 in Bg 250 but there was no effect of soil moisture condition. The reason for this may be due to the variation of genotypic characters. The results are supported by Singh and Gangwer (1989) who opined that varietal differences regarding the number of grains might be due to their differences in genetic constituents.

Filled grain percentage

Soil moisture condition x variety interaction had no significant (P>0.05) effect on %filled grain. Similarly, %filled grain was not significantly (P>0.05) influenced by the soil moisture condition. However, %filled grain was significantly (P<0.05) influenced by the variety where Bg 252 had the highest %filled grain and Bg 250 recorded the lowest (Table 1).

Ying *et al.* (2009) also reported that grain filling was affected by cultivar. Their results indicated that cultivar with small panicle size generally filled well whereas the tropical japonica with large panicle size filled poorly. Among the rice varieties tested, Bg 250 had bigger seeds that were not filled well relative to the smaller seeds of Bg 252.

Grain yield per pot

No significant (P>0.05) interaction effect between soil moisture condition and variety was observed in terms of grain yield per pot (Table 1). Similarly, the grain yield was not significantly (P>0.05) influenced by the variety. However, soil moisture condition greatly influenced the grain yield. Flooded condition produced significantly (P<0.05) higher grain yield compared to aerobic condition. Among the varieties cultivated in aerobic condition Bg 250 produced higher yield. Therefore, it could be identified as the best variety which can be cultivated in aerobic condition.

Grain Sterility Index (GSI)

The results revealed that there was no significant (P>0.05) interaction effect between soil moisture condition and variety on GSI (Table 1). Similarly, GSI was not significantly (P>0.05) influenced by soil moisture condition because aerobic condition provided the ample amount of soil moisture.

However, rice varieties were differed significantly in terms of GSI, where Bg 250 had the highest value and Bg 252 had the lowest irrespective of soil moisture condition.

Table 1: Yield performances of three ultra-short age rice varieties (Bg 250, Bg 252 and Ld 253) under aerobic and flooded condition. Means with the same letters in each column are not significantly different at 0.05 probability level.

Parameter	No. of panicles per pot	Spikelets per panicle	Yield per pot (g)	%Filled grain	Grain Sterility Index
Soil moisture					
Flooded	16.6a	94.6a	15.39a	85.5a	0.132a
Aerobic	13.5b	83.2a	11.1b	80.8a	0.211a
Variety					
Bg 250	15.1a	81.2b	15.77b	73.2b	0.232a
Bg 252	14.7a	82.9b	11.93b	94.1a	0.103b
Ld 253	15.4a	102.7a	12.05a	89.2a	0.179ab
Pr>f (Soil moisture)	0.040*	0.062	0.005*	0.097	0.067
Pr>f (Variety)	0.921	0.003*	0.052	0.000*	0.024*
Soil moisture*variety	0.998	0.732	0.640	0.667	0.130

* Significantly different at 0.05 probability level

Relationship of canopy temperature (CT) with growth, yield, grain sterility and pollen fertility

The average near canopy temperature dynamics of rice in a typical day during flowering period is shown in the Figure 5. Anthesis (spikelet opening) of rice occurs from 09:00 to 12:00 h (Prasad *et al.*, 2006). However, rice varieties differed in time of spikelet opening. Spikelets of the three rice varieties Bg 252, Bg 250 and Ld 253 started to open at 09:15 h, 09:45 h and 10:45 h, respectively but time of peak opening occurred within 09:00 to 11:00 h.

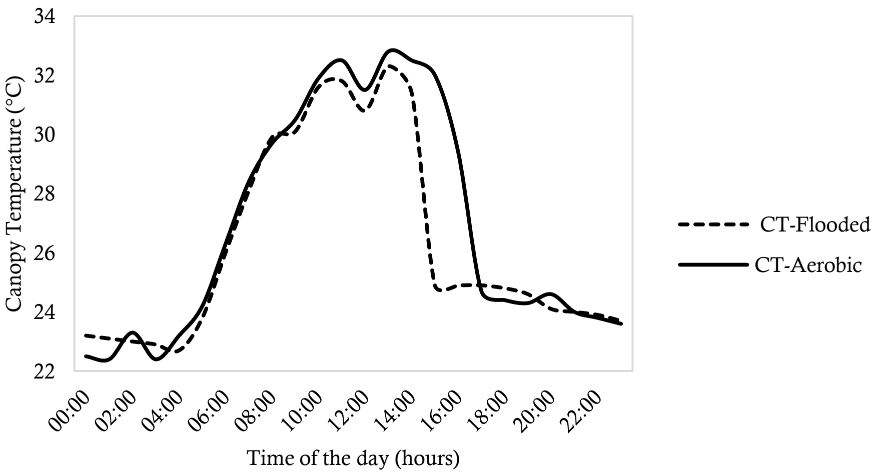


Figure 5: Average near canopy temperature dynamics of rice in a typical day during flowering period.

Effect of CT on growth parameters

The results of correlation analysis of growth parameters such as height, number of tillers, culm diameter with maximum CT and minimum CT are presented in the Table 2. In both aerobic and flooded conditions there was a significant ($P<0.05$) negative correlation between maximum canopy temperature and number of tillers per pot (Table 2). Height was significantly ($P<0.05$) and positively correlated with minimum canopy temperature under both moisture conditions (Table 2). Culm diameter showed a negative correlation with maximum canopy temperature but it was not significant ($P>0.05$), as shown in Table 2.

Table 2: Relationship between canopy temperature (CT) and growth parameters of three rice varieties (Bg 250, Bg 252 and Ld 253) under two soil moisture conditions (Aerobic and Flooded conditions). CT_{max} – Maximum Canopy Temperature. CT_{min} – Minimum Canopy Temperature.

Growth parameter	Moisture condition	Correlation coefficient	
		CT_{max}	CT_{min}
Height	Aerobic	-0.62	0.92*
	Flooded	-0.63	0.92*
No. of tillers per pot	Aerobic	-0.97*	0.56
	Flooded	-0.93*	0.61
Culm diameter	Aerobic	-0.36	0.21
	Flooded	-0.58	-0.34

*Significant correlation ($P<0.05$).

Effect of CT on grain yield

Under flooded condition, grain yield was significantly ($P<0.05$) and negatively correlated with CT_{max} at around 13:00 h (Table 3). However, there was no correlation between CT_{max} and rice yield under aerobic condition. CT is a relative indicator of canopy transpiration as well as level of plant stress (Guendouz *et al*., 2012). When CT reaches a maximum, transpiration may reach a minimum due to stomatal closure. Consequently, photosynthesis would also decrease leading to yield penalties. Wani *et al.* (2013) reported that increase in temperature greater than 2 °C beyond the critical level reduced the rice yield by 0.75 t ha^{-1}.

Effect of CT at spikelet opening and closing on pollen fertility and grain sterility

Average %pollen fertility showed a highly negative correlation with CT at spikelet opening in both aerobic and flooded conditions. There was no any impact by CT at spikelet closing on %pollen fertility (Table 4). According to Weerakoon *et al*. (2008), increasing spikelet temperature above 31 °C gradually increases the pollen sterility and temperatures; above 36 °C with high relative humidity (85%) can completely sterile pollens of rice. This may be due to high temperature-induced desiccation occurred in pollen grains.

Table 3: Relationship between maximum canopy temperature (CT_{max}) and grain yield of three rice varieties (Bg 250, Bg 252 and Ld 253) under two soil moisture conditions (Aerobic and Flooded).

Moisture condition	Correlation coefficient
Aerobic	-0.23
Flooded	0.69*

*Significant correlation (P<0.05)

Temperature at the time of spikelet opening to 03 h from spikelet opening is important for high-temperature stress induced spikelet sterility (Satake and Yoshida, 1978). Therefore, CT at 09:00 h to 13:00 h (maximum temperature) were critical for grain sterility. The results of the correlation analysis revealed a highly positive correlation between grain sterility and CT at spikelet opening. There was no any impact by CT at spikelet closing on grain sterility (Table 4).

Table 4: Relationship between canopy temperature (CT) spikelet opening and closing on pollen fertility of three rice varieties (Bg 250, Bg 252 and Ld 253) under two soil moisture condition (Aerobic and Flood).

CT	Moisture condition	Correlation coefficient	
		Pollen fertility	Grain fertility
CT at spikelet opening	Aerobic	-0.76*	0.95*
	Flooded	-0.80*	0.85*
CT at spikelet closing	Aerobic	-0.47*	0.14
	Flooded	-0.34*	0.32

*Significant correlation (P<0.05)

Spikelet fertility percentage under aerobic and flooded conditions

The interaction between soil moisture condition and variety was not significant for the spikelet fertility at 14 d after anthesis (Table 5). Fertile and sterile spikelet percentages were significantly (P<0.05) influenced by the soil moisture condition and variety. Flooded condition recorded the highest fertile spikelet percentage compared to aerobic condition. Bg 252 recorded the highest fertile spikelet percentage while Bg 250 recorded the lowest. An increase in spikelet sterility under moisture stress conditions was also reported by Raman *et al.* (2012) and Botwright Acuña *et al.* (2008). Aerobic condition recorded the highest %sterile spikelet compared to flooded condition. Bg 250 recorded the highest %sterile spikelet, while Bg 252 recorded the lowest.

Table 5: Percentage of spikelet fertility/sterility of three rice varieties (Bg 250, Bg 252 and Ld 253) at 14 d after anthesis under aerobic and flooded conditions.

Parameter	Fully fertile spikelets (%)	Partially fertile spikelets (%)	Sterile spikelets (%)
Soil moisture			
Flooded	85.3a	3.1a	11.60b
Aerobic	77.9b	2.3a	19.78a
Variety			
Bg 250	70.5c	4.0a	25.50a
Bg 252	93.2a	1.5a	5.27c
Bg 253	81.1b	2.5a	16.40b
Pr>f (Soil moisture)	0.001*	0.45	0.003*
Pr>f (Variety)	0.000*	0.18	0.0001*
Pr>f (Soil moisture*variety)	0.37	0.68	0.27

*Significantly different at 0.05 probability level (Means followed by the same letters in each column are not significantly different at 0.05 probability level).

The highest sterility was found at the bottom portion and lowest at the top portion of panicle, whereas middle portion of panicle showed an intermediate level of sterility. Cheng *et al*. (2003) also reported high sterility in inferiorly located spikelets. In general, inferior spikelets flower later, exhibit a slower rate of increase in dry weight during grain development and a lower grain weight than superior spikelets (Yang *et al*., 2006; Dong *et al*., 2014).

CONCLUSIONS

Present study supports for the claim that monitoring near canopy temperature (CT) dynamics is a useful tool to assess the growth and yield performances of rice under varying soil moisture conditions. As evident by this study, CT at spikelet opening shows a positive impact on grain sterility and negative impact on pollen fertility irrespective of moisture condition. Furthermore, grain yield negatively correlates with maximum canopy temperature (CT_{max}) at 13:00 h under flooded condition. CT effect on vegetative growth parameters were also observed in this study, where CT_{max} negatively influences on number of tillers per pot and minimum canopy temperature (CT_{min}) positively influences on plant height. In general, rice plants under flooded condition performed well in all growth and yield parameters compared to aerobic condition. Among the three varieties, Bg 250 partitioned more dry matter into panicles than Bg 252 and Ld 253 at maturity stage resulting in higher grain yield. Among those three ultra-short age varieties, Bg 250 variety can be identified as the best performing variety even under aerobic condition.

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